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Disease-a-Month

Poliomyelitis

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had his academic training, leading to M.D. and Ph.D. degrees, at the University of Minnesota where, since 1946, he has been Professor and Director, Division of Neurology, in the Medical School. In the field of neuropathology he has conducted studies of the various encephalitides and bulbar poliomyelitis. Dr. Baker is active as consultant and adviser to numerous groups concerned with special problems in neurologic disease, among them, multiple sclerosis, cerebral palsy and poliomyelitis.

POLIOMYELITIS is an infectious disease caused by one of the smallest of the filtrable viruses. Until fairly recently it was believed that the virus had a very limited host range. However, studies have shown that experimental infection can be produced in rodents and in most species of primates, and the brilliant studies of Enders and his group have proved that the virus can be grown in vitro in non-nervous tissue and in tissue culture. Many strains of poliomyelitis viruses have been isolated from all parts of the world. These many strains can be divided into three immunologically distinct types, and infection with one type does not protect against reinfection with one of the other types. The existence of three such distinct types probably accounts for many of the cases of reinfection in this disease. The three types of virus are known as type I, or Brunhilde; type II, or Lansing, and type III, or the Leon. Although epidemiologic surveys are incomplete, it would appear that all three types are world-wide in distribution and that one or another of the types may pre-

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dominate in any single outbreak of this disease wherever it occurs.

SOURCE OF INFECTION AND MODE OF SPREAD.—In spite of extensive investigation, the mode of spread and manner of transmission of this disease has not been accurately worked out. It would appear that the human being no doubt serves as the reservoir of the virus and that the disease is spread by intimate human contact. It is known that the virus is present in the throat and intestine of both overt and silent cases of infection and that large amounts of virus are excreted in the stools 12–20 days before the onset of the illness and for weeks afterward. The apparent multiplication of the virus in the alimentary tract and its excretion in the stools strongly suggest the chief medium for the virus transfer in man. It would strongly point up the need for careful body hygiene, particularly of the hands in children, during the period when poliomyelitis is most prevalent.

Extra-human sources of infection may act as an accessory mode of transfer of the virus, particularly in the occasional sporadic case of the disease. The virus excreted by man has been shown capable of infecting water, milk and food. It may also infect feces-feeding flies which in turn have been shown to contaminate food. The virus may persist in sewage a long time and may survive ordinary methods of sewage purification.

The regular presence of the virus in the walls of the pharynx, ileum and intestinal contents would seem to indicate that the alimentary tract may be the first site of infection. The virus probably reaches the alimentary tract through the mouth by way of contaminated food or hands or from pharyngeal excretions and establishes itself throughout the alimentary tract, chiefly the pharynx and small bowel, where the virus grows.

It is not completely clear how the virus spreads from the gut to the central nervous system. Formerly it was believed that the virus spread along the afferent fibers from the intestines by way of the abdominal sympathetic ganglions to the spinal cord. However, recent observations on the presence of the virus in the blood stream (viremia) have suggested that the virus may well reach the nervous system secondary to a blood stream infection.

PREDISPOSING FACTORS.—Among the factors predisposing to poliomyelitis, age has always been considered the most impor-

tant. Heretofore, most cases occurred in children under 10 years of age. Within recent years, however, there has been a definite shift to individuals at the beginning of adult life. The disease is rare in infants under 6 months of age, although newborn infants have been reported to be susceptible. Sex does not seem to influence the occurrence of this illness.

Geographic distribution appears to have no role in the disease. Although the majority of cases do occur in temperate climates, poliomyelitis has a world-wide distribution, having been reported in the tropics as well as in Iceland and Alaska.

Epidemics of poliomyelitis recur with considerable regularity during the summer in temperate areas. On the basis of immunologic studies, it is believed that the disease persists throughout the year, with the highest incidence of overt appearance during the late summer and early fall. Active cases may continue to appear into early winter.

Strenuous exercise, chilling and pregnancy all seem to predispose to the disease.

It is generally accepted that tonsillectomy performed during the time the disease is prevalent predisposes to the more severe and bulbar forms. There is also suggestive evidence that any type of prophylactic vaccination given at such times may predispose to infection with poliomyelitis.

INITIAL PHASE

This disease apparently implicates all parts of the nervous system and therefore can result in a large variety of symptoms and signs. Only through a thorough understanding of the clinical symptomatology can one anticipate the complications of this illness and offer the patient the benefits of the newer developments in the treatment of this disease. In the following discussion, most of the emphasis will be placed on the more acute manifestations of the illness. Treatment procedures related primarily to the chronic muscle disabilities will be mentioned only briefly since they fall primarily into the realm of orthopedics and physical medicine and rehabilitation.

The onset of poliomyelitis is usually acute, and the initial

symptoms are fairly mild, although they may be severe and alarming. The most common prodromal symptoms and signs are nonspecific and consist of mild headache, fever, malaise, sore throat, nausea and vomiting, diarrhea, restlessness and drowsiness. There are three well recognized types of symptoms which vary in frequency from epidemic to epidemic and consist of (1) upper respiratory symptoms, (2) gastrointestinal symptoms, and (3) meningeal symptoms. Signs and symptoms of an upper respiratory infection occur in about one third of all cases, although in some outbreaks they may comprise the predominant symptomatology. The gastrointestinal complaints usually consist of diarrhea, often associated with nausea, vomiting and abdominal pain. Generally the meningeal symptoms at this stage of the illness are very mild but are usually frequent, with headaches and some rigidity of the neck muscles being present in a large number of cases. The temperature rises slowly, reaching its peak in two to three days, and then rapidly subsides. Fortunately, over two thirds of the patients who manifest these clinical syndromes recover and remain well after the initial period of illness (1–3).

Unfortunately not all cases have such a benign course. In some individuals, particularly children, a "dromedary" course is seen which includes a brief period of remission between the prodomata and the onset of actual invasion of the nervous system (4, 5). In others, particularly adults and in children who develop bulbar involvement, the illness assumes a more rapid course, with the prodromal symptoms being followed directly by severe paralysis.

The onset of clinical evidence of central nervous system involvement is usually manifested by a return or an accentuation of the anorexia, fever and headache. Severe pain in the back and extremities is complained of early. The pain is accompanied by extreme sensitivity to all forms of stimuli. Accompanying this pain and muscle tenderness are such evidences of meningeal irritation as stiff neck, irritability and/or fretfulness. The temperature rises considerably, to 101–104 F., and there are often drowsiness and apathy associated with the irritability. Convulsions are infrequent, but may occur in infants.

Physical examination at this stage of the illness will reveal

striking findings, the most pronounced being stiffness of the neck and back muscles. The muscles of the extremities may be similarly involved, resulting in certain limitations in the motion of the limbs and an abnormal positioning of the extremities by the patient. Muscle fasciculations as well as increased reflexes may at this stage indicate an irritative process within the spinal cord.

Pain in poliomyelitis, when spontaneous, is usually located in the nuchal and lumbar regions and in the calves and thighs. More commonly, however, pain is not spontaneous but is precipitated by passive motion of the extremities or by pressure on the muscles.

During the acute stages of poliomyelitis, there may occur many vasomotor disturbances of the skin and the extremities such as mottling and flushing. The affected limbs are frequently cold and show purplish mottling or even mild edema. Sweating, either localized or generalized, may also be present.

There is no consistent change in the blood picture. Leukocytosis of a slight to moderate degree, with increase in polymorphonuclears, is usually present at this stage of the illness. Occasionally leukocyte counts as high as 25,000 are observed. The sedimentation rate is usually normal.

The spinal fluid shows pleocytosis during the acute phase of the illness, the average cell count being 50–150 per cu. mm., although the count may be as high as 2,000. Initially, polymorphonuclears may predominate, but lymphocytosis is more common. The cell count returns to normal within two to three weeks. At the onset, the spinal fluid protein content is normal but may become increased by the second week of the illness and may remain elevated for many weeks (6).

TREATMENT.—Treatment of this stage and type of poliomyelitis includes complete bed rest, isolation and careful observation. Of most importance is the bed rest, and this should be continued until after the fever has subsided. Routinely, the temperature, respiration and pulse should be recorded every four hours and the blood pressure every morning during the acute illness. Frequent careful check of the patient for any evidence of limb paralysis, respiratory distress or bulbar symptomatology is imperative.

The relief of pain and restlessness is a vexing problem, and there is no medication entirely suitable. The patient should be permitted to assume whatever position he wishes during the first few days of the acute febrile period. As the tenderness and pain subside, he should be made to lie flat on his back on a relatively firm bed with his feet against a footboard. Vigorous hot-packing in this early febrile stage should be avoided. The administration of drugs also should be avoided during this acute stage. The use of relatively mild sedatives such as chloral hydrate, paraldehyde and barbiturates is exceedingly dangerous and should be avoided, if possible, until one is sure of the degree of motor involvement. Salicylates in moderate doses and local heat may relieve pain. Methadone hydrochloride, in our experience, may be used in small doses of 5 or 10 mg. and often ameliorates restlessness and anxiety.

During the first few days and occasionally for several weeks, there may be urinary retention. If catheterization and small doses of Prostigmin are not effective, an indwelling catheter must be used. Gantrisin, 0.5 Gm. three times a day, is used prophylactically, and urinalysis is performed three times weekly to check for signs of cystitis. A fluid intake of 3,000 cc. daily is recommended unless there is danger of pulmonary edema or cardiac failure.

Adequate nutrition is also important during the acute illness. If the patient is unable or unwilling to swallow, parenteral fluid therapy may be used for a few days. After the acute phase, nasal feedings may be instituted, with frequent small feedings, but possible regurgitation must always be considered, and if the stomach is atonic, food may accumulate.

Constipation, if present, should be treated by enemas. Examinations for fecal impaction may be needed. Ileus and abdominal distention may also occur and require prompt attention.

SPINAL POLIOMYELITIS

The spinal form of poliomyelitis is the most common. The chief pathologic finding is destruction of motor cells in the spinal cord, with weakness or paralysis of the related muscle group (7–9).

Within a short time after the appearance of signs and symptoms indicative of central nervous system involvement, namely, headache, stiff neck and irritability, there will develop in a number of cases definite evidence of involvement of the segmental motor apparatus of the spinal cord. At the onset there are some irritative phenomena such as fasciculations, perhaps even increased tendon reflexes, and local pain and tenderness in select cord segments. Later the reflexes become diminished or are lost, and weakness develops, followed by paralysis. The paralysis usually appears on the second or third day after the evidence of central nervous system involvement, but may be immediate in onset or may even be delayed until the seventh or eighth day. Frequently the motor involvement reaches its maximum within a few hours, but may progress for days. In rare instances, after remaining stationary for days, the paralysis may again progress over a period of days.

The distribution and severity of the palsy vary and usually are not symmetrical. All grades of severity may occur, from transient weakness, which is difficult to evaluate and soon disappears, to complete and permanent paralysis. As a rule, if one muscle is paralyzed, other muscles innervated by the same cord segment will show some degree of involvement. The paralysis is always of a lower motor neuron type and shows diminished consistency of muscles, loss of tonus, absence of deep reflexes and, finally, some atrophy.

The lower extremities are more often affected than the upper, and the onset is usually in the proximal muscles, with the spread distally. In the leg, the quadriceps femoris is perhaps the most frequently affected. There is often severe involvement also of the peroneals and the foot flexors. The muscles of the hip joint such as the iliopsoas and gluteals are frequently implicated. In the upper extremities, the proximal muscles are by far most frequently and often irregularly involved, often including the muscles that derive their innervation from the fifth and sixth cervical level, namely, the deltoid, the flexors of the elbow and the supinator of the forearm. Even with severe involvement of the upper limbs, the distal musculature of the hand and fingers may be spared.

The muscle weakness remains unchanged for a period of weeks after the acute illness has subsided. It then begins to improve and continues to do so for a period of months. Most improvement can be expected to occur during the first six to nine months, but some increase in muscle power can be expected up to 18 months. Spontaneous recovery should not be anticipated after this time. In most cases, the most severely involved muscles will show the least tendency to recover, while muscles that are only paretic have an excellent chance of becoming useful and functional.

Within a few months after the development of severe paralysis, the involved muscles begin to show definite evidence of atrophy. The degree of atrophy will depend upon the severity and permanency of the muscle paralysis. Completely involved muscles will undergo severe atrophy, with complete disappearance of the muscles and replacement by fibrous tissue.

In spinal poliomyelitis, innumerable types of skeletal deformities may occur as a result of the following factors: (1) a lack of muscle balance resulting from the paralysis, (2) shortening of the mildly involved muscles due to irritation (muscle tightness or "spasm"), (3) fibrosis of the completely destroyed muscle, (4) facial contractures, (5) poor positioning in bed because of the resistance of sensitive muscles to stretching, and (6) accentuation of bad positioning owing to the effect of gravity (10–12). No attempt will be made to enumerate all the possible deformities which may develop. Such deformities have long been recognized and are well covered in texts on orthopedics and physical medicine. However, it is imperative that the physician caring for a patient with an acute or subacute case of spinal poliomyelitis be aware of the factors that cause such deformities so that certain general treatment procedures may be instituted in order to prevent their occurrence. It must be kept in mind that if any deformity is maintained, the shortened muscles develop a contracture and the position of the limb becomes fixed. Furthermore, the deformity often inhibits the function and recovery of the muscles in the overstretched position. For this reason, management designed to avoid such deformities must be instituted early in the care of these patients.

Treatment.—Good nursing care is of primary importance. The patient should be made comfortable in such a position that avoids or at least minimizes the deformity. The bed should be firm, with a board under the mattress. These simple measures of posturing in bed should be continued during the acute stages of the illness, with emphasis on good nursing and gentle handling. When convalescence begins, passive motion can be introduced to prevent contractures and to oppose shortening of muscles. Such exercises are directed toward increasing the range of motion in the joints and reducing bad positional attitudes. Moist heat usually makes the patient more comfortable and reduces the sensitivity of the muscles. Application of such moist heat should precede passive exercises. Guided assistive exercises are combined with passive motion and are increased as muscle strength returns. These active exercises are directed toward the paretic or weak muscles. The degree, intensity and time devoted to such therapeutic procedures will depend upon the degree of involvement. A description of the more complicated maneuvers to improve muscle function and prevent deformities is outside the scope of this discussion, falling more properly into the field of physical rehabilitation and orthopedics.

Complications Other Than Peripheral Muscular

Because of the immobilization induced by the paralysis, patients with purely spinal poliomyelitis may have a number of other complications which must be watched for and avoided by the institution of proper therapeutic procedures.

Thrombophlebitis.—Prolonged immobilization because of the paralysis not uncommonly results in thrombosis of the large veins of the lower limbs—the femoral, iliac and pelvic. Many factors play a role in this complication. Probably the most important is the pronounced venous stasis resulting from the prolonged bed rest and associated with the systemic infectious process. Equally important, however, is the local injury to the vessel endothelium occurring during routine nursing care or resulting from too enthusiastic physical therapy (13).

The symptoms may be mild or severe. Pain in the involved

limb is one of the most constant complaints. It may be mild and well localized, or it may involve the entire extremity and be throbbing in nature. Often the thrombosed vessel can be palpated. There may be local tenderness in the calf or thigh with pain on forced flexion. Gentle but forceful dorsiflexion of the foot with the leg extended will cause severe pain (dorsiflexion sign). The involved limb may become edematous, with mottled cyanosis.

The most frequent complication of thrombophlebitis is *pulmonary embolism.* Large emboli produce fatal pulmonary embolism which may occur suddenly in a patient who is recovering nicely from the infectious process. Smaller emboli produce pulmonary infarcts or abscesses, manifesting themselves in sudden chest pain associated with uncomfortable breathing and, less commonly, blood-tinged sputum. These symptoms, too, may occur abruptly in a patient who apparently is convalescing well from the poliomyelitis and may be the first indication that thrombophlebitis had occurred.

In spinal poliomyelitis, thrombophlebitis must be avoided by instituting proper preventive measures during the early acute phases of the illness. Proper venous circulation should be maintained by moderate flexion and extension of the limbs early in the illness. Excessive dehydration should be avoided. In all cases, the limbs must be handled gently, and constant attention must be given to the avoidance of injury or bruising of the limbs and too severe stretching during physical therapy. Anticoagulants such as Dicumarol can be helpful in minimizing this complication.

Once the thrombus has formed, every attempt should be made to prevent pulmonary embolism. Movement or massage should be absolutely forbidden, and the involved extremity should be elevated to avoid edema. Local heat may be applied by use of a cradle. Anticoagulants are very helpful. Dicumarol is the drug of choice since it can be given over a long period of time in doses that keep the prothrombin time at about 2.5 to 3 times normal.

RENAL CALCULI.—Diseases such as poliomyelitis which lead to prolonged immobilization in a prone position are frequently complicated by urinary lithiasis. This urinary tract complication

is of utmost importance, since it may result in decrease of kidney function and death from uremia in a patient who, from the point of view of the poliomyelitis, may be progressing very favorably. Factors which may lead to stone formation include: (1) hypercalcemia from disuse osteoporosis, (2) stasis in the dependent renal calices, (3) overconcentration of urine from dehydration, (4) alkalization of the urine (diet, medication, infections with urea-splitting bacteria), (5) vitamin A deficiency, and (6) infection from foreign bodies in the urinary tract (catheters) (14).

It is imperative in all such patients to exercise great care to prevent the development of lithiasis. Preventive procedures must be instituted as soon as the patient becomes immobilized. Once the formation of lithiasis has begun, treatment is of little value.

Osteoporosis and the consequent hypercalcemia may be minimized by the use of active and passive exercise and by frequent and early moving and turning of the patient. Stasis in dependent calices may be counteracted by allowing the patient to spend definite periods in the upright position, even though he requires elaborate support. Concentration of the urine can be prevented by supplying a fluid intake that will insure an output of 2,000 cc. daily. The reaction of the urine can be controlled by using an acid-ash diet (avoidance of citrus fruits and leafy vegetables). Absorption of large amounts of calcium can be avoided by reducing the use of acids or acid salts and by avoiding ingestion of large amounts of vitamin D (no milk). Basic aluminum carbonate jel (Basaljel, 30 cc. four times daily) is often helpful in minimizing the excretion of phosphorus in the urine and thus reducing the urinary concentration of one of the most important constituents of the stones. Infection of the urinary tract must be prevented. Effort should be made to keep all catheters, glassware and tubing carefully clean and sterilized effectively. Antibiotics in small doses are prescribed routinely whenever an inlying catheter is used.

IMPAIRED MUSCLES OF RESPIRATION.—The diaphragm and intercostal muscles are innervated by the motor neurons of the upper thoracic and cervical cord. They control the rhythmic expansion and contraction of the thoracic cage. Effective ventila-

tion is determined by the magnitude of tidal volume; hence slow deep breathing is far more effective in ventilating the alveoli than rapid shallow breathing. In poliomyelitis there is frequently a partial or even a complete involvement of the muscles of respiration, and it is extremely important that the physician be alert to detect or anticipate its occurrence early. In some patients, complete paralysis may occur so rapidly that corrective measures, using the respirator, are not immediately available, thus resulting in a fatal outcome. Much more important is the partial or mild involvement of these respiratory muscles which can be overcome by more rapid but shallower respirations and a consequent smaller alveolar exchange. This underventilation may result in mild hypoxia in the absence of cyanosis and may be overlooked unless specifically sought.

There are a number of clinical symptoms and signs that suggest an impending or actual inadequacy of the muscles of respiration and should be watched for constantly in every case of poliomyelitis. Paresis or paralysis of the deltoid or biceps muscles, both of which are supplied by neurons situated close to the cells innervating the diaphragm, is always an important danger signal in rapidly progressing poliomyelitis and should alert the physician to the possibility of an impending respiratory crisis. Involvement of the muscles of respiration may become manifest by irregularities in the rate and rhythm of respirations. Respirations become rapid and shallow, with flaring of the alae nasi. There soon develops an asymmetry of the movement of the thorax, particularly on deep inspiration. Often respiration appears to be entirely abdominal, with bulging and retraction of the epigastrium. In severe involvement of the intercostal muscles, there is an absence of the normal successive retraction of the lower intercostal spaces during inspiration (Litten's sign). Unilateral paralysis of the diaphragm is often difficult to diagnose clinically without the use of fluoroscopy. However, on quiet respiration one can frequently observe or detect by palpation the absence of excursion on the involved side. Bilateral diaphragmatic weakness is more readily evaluated. The abdomen cannot be protruded, and various expulsive acts such as coughing, sneezing and sniffing cannot be carried out.

When both diaphragm and intercostal muscles are implicated, the accessory muscles are used for deep inspiration. This is readily observed. The patient becomes unable to repeat three or four numbers without pausing for breath and is unable to hold the breath for 15 seconds. Normally, a child can hold his breath for 15–18 seconds.

If the respiratory difficulty is not properly treated, the patient soon becomes restless, apprehensive and sleepless. The pulse rate and blood pressure increase and the patient tends to speak fewer words in one breath. Severe respiratory impairment will eventuate in cyanosis, confusion and loss of consciousness.

It should be pointed out that difficulty in breathing, particularly of exhalation, may result without actual paralysis of the respiratory musculature. Tightness and shortening of the intercostals and diaphragmatic or abdominal musculature can upset the respiratory rhythm. Even severe anxiety without actual muscle weakness can account for marked disturbances in respirations.

When respiratory muscle function is definitely lost, some form of mechanical respiratory aid is necessary. Three aids are the tank respirator, the cuirass respirator and the rocking bed. Of these, the tank respirator is by far the most efficient and generally is used during the acute illness. Patients with respiratory difficulty are often tense and apprehensive; hence the physician should prepare the patient for the respirator and should remain with him for some time after he has been placed in it. As soon as the patient is placed in the respirator, its rate and pressure must be adjusted to the patient's needs. In general, alterations in depth are more beneficial than alterations in rate. Under proper regulation, all such signs of hypoxia as apprehension, anxiety and restlessness should disappear.

The patient should be transferred to a chest respirator or to the rocking bed as soon as possible. Generally these are not effective in severe acute respiratory paralysis. Their best application is for the convalescent patient who no longer requires the tank respirator but still needs some respiratory assistance. Early transfer to either the cuirass respirator or rocking bed is very important, since it facilitates the care of the patient and enables more intensive physical therapy.

BULBAR POLIOMYELITIS

Most deaths in poliomyelitis can be related to involvement of the brain stem and immediately contiguous brain centers. On the basis of clinical symptomatology, supported by pathologic observations, it is possible to divide bulbar poliomyelitis into three groups: (1) the cranial nerve group, (2) the respiratory center group, (3) the circulatory center group. Although they are best described according to their predominant symptomatology, it must be emphasized that they rarely occur in pure form but usually merge into each other (15–18).

Cranial Nerve Involvement

This is the commonest symptomatology of bulbar poliomyelitis. Involvement of the upper cranial nerve group includes the third to the eighth cranial nerves and has been referred to as polioencephalitis superior. Isolated ocular palsies as well as total external ophthalmoplegias may occur in poliomyelitis. Sixth nerve palsies are the most common of the ocular involvements, but any type of partial or complete third nerve involvement may also be present (19). Nystagmus and conjugate deviation of the eyes may also occur. Pupillary disturbances, including Horner's syndrome and hippus, have also been reported.

Disturbances of mastication may result from damage to the motor portion of the fifth cranial nerve (20). Palsies of the fifth nerve may be unilateral or bilateral and may involve part or all of the muscles supplied by the fifth nerve. Examination may reveal that the patient is unable to close his mouth, but in less severe cases it may be necessary to test the movements against resistance. With unilateral lesions of the fifth nerve, the jaw may deviate spontaneously when the patient opens his mouth; at other times the action of the pterygoid muscles must be tested by sideward deviation of the jaw against resistance.

One of the most interesting and important clinical disturbances of the fifth cranial nerve in bulbar poliomyelitis is trismus. This complication appears suddenly, usually at the end of the first week of the illness, and persists from five to seven days. At times the trismus is extremely painful. The jaws become locked,

and eating or even talking becomes impossible. This complication may be extremely serious, since inability to open the mouth prevents adequate removal of secretions, leading to possible obstruction of the airway. In such cases, immediate tracheotomy is often necessary to prevent asphyxiation by secretions.

In some patients, involvement of the muscles of mastication is not detected until months have elapsed, at which time difficulty in chewing or actual atrophy of the muscles and facial asymmetry first become apparent. The progressive atrophy of these muscles is occasionally accompanied by fibrosis which limits opening of the mouth.

Paralysis or paresis of the facial musculature is fairly common in bulbar poliomyelitis. In some cases, the entire distribution of the facial nerve is involved; in others, only one branch is affected, such as that which supplies the cheek, the forehead or the lips; finally, in still others, the involvement is patchy, implicating one group of muscles on one side and another set on the opposite side. A number of patients will have complete facial diplegia.

Bilateral deafness as well as vestibular disturbances, chiefly vertigo, have been reported in poliomyelitis.

The disturbances of the upper cranial nerves usually hold no threat to life. They may, however, be annoying and the residuals may produce definite handicaps. They are important because they should make the physician alert to the possibility of the involvement of more vital centers. If the symptoms remain strictly localized to the upper cranial nerves, the prognosis is good and very little therapy is indicated.

By far the most frequently involved of the cranial nerve nuclei in bulbar poliomyelitis is the tenth, or the nucleus ambiguus. This results in weakness of the soft palate, the pharynx, the larynx and the vocal cords. Initially there is difficulty in swallowing, accumulation of secretions in the oropharynx and/or hoarseness or a nasal twang to the voice. The most dangerous and the most easily recognized disturbance is the difficulty in deglutition. This complication is fairly easily recognized. Early there is an unusual amount of drooling and the patient constantly attempts to clear the throat. Secretions begin to pool in the throat and

may become so profuse that one is forced to think of the possibility of excessive secretions of saliva. With involvement of the vocal cords, the voice becomes hoarse or develops a nasal twang. Laryngeal stridor may be present. Weakness of the tongue may be unilateral or bilateral and may impede swallowing or expectoration of saliva. Weakness of the sternocleidomastoid and trapezius muscles occurs but is not of much immediate importance. With involvement of the lower cranial nerves, there is a constant threat to the airway from accumulation of secretions. A further threat to the airway results from aspiration of fluid or food into the larynx or from reflex spasm of the glottis. Such obstruction of the airway should be watched for carefully; it is manifested early by evidence of hypoxia such as restlessness, apprehension, sleeplessness and increasing pulse rate and respiratory effort. If the obstruction is not relieved, laryngeal stridor, dyspnea, cyanosis and severe encephalitic symptoms develop.

When the patient develops difficulty in swallowing, it is imperative that the airway be kept open. This should be attempted at first by postural drainage and mechanical suction. If all other methods fail to keep the airway open, one may have to resort to tracheotomy. If tracheotomy is done, a number of precautions must be observed. (1) The stomach should be aspirated before surgery to avoid aspiration of the contents. (2) The tracheotomy should be done high in the neck to allow better care of the patient. (3) The tracheotomy tube must be large, generally a six or eight tube. (4) After tracheotomy, the patient still requires constant care and supervision.

ABDUCTOR PARALYSIS OF THE VOCAL CORDS.—An occasional patient has rapid development of bilateral abductor paralysis of the vocal cords. There is a warning stridor followed by sudden cyanosis and coma. In such cases, the immediate insertion of a Mosher tube can be life-saving. This must be followed by tracheotomy.

ASPIRATION OF SECRETIONS OR FOOD.—This complication occurs frequently with involvement of the lower cranial nerves. If small areas of the lung are involved by atelectasis, no signs or symptoms develop. However, if enough pulmonary tissue is affected, there is a sudden onset of dyspnea, cyanosis and tachy-

cardia. The respiratory movements on the involved side are diminished or absent and the affected side looks flat. The respiratory sounds may be decreased or absent and on percussion the sounds are flat. Coarse râles may be heard. The diaphragm may be elevated and the mediastinum dislocated toward the involved side. The diagnosis is readily verified by roentgen examination of the chest.

This very serious complication requires intensive therapy. The obstructing material must be removed by mechanical suction or by bronchoscopy. The latter is easily carried out through a tracheotomy tube. Vigorous antibiotic therapy should be used to prevent pneumonia or abscess formation.

SPINOBULBAR INVOLVEMENT.—A large number of patients with severe cranial nerve involvement also have damage to the cervical and thoracic segments of the cord. The symptomatology, in addition to the cranial nerve palsies with dysphagia, consist of severe respiratory embarrassment due to paralysis of the intercostal muscles and diaphragm. This combined involvement presents specific therapeutic problems which are not encountered in isolated involvement of either spinal cord or medulla. Because the muscles of respiration are affected, these patients must be placed in a respirator. It is imperative to insure an open airway. These patients must be watched very carefully to be sure that obstruction does not occur. Constant suction should be maintained, and if it appears that the airway cannot be kept open by suction, tracheotomy must be done. Often it is very difficult to use tracheotomy in these patients because the tank respirator does not allow enough neck space for care of the tracheotomy. For this reason, in many areas positive pressure respirators are being used for patients with tracheotomies. The positive pressure respirator can be attached directly to the tracheotomy tube. This eliminates the rigid confinement within the tank and allows for much better care of the patient. It also enables one to care better for the tracheotomy, which is now readily accessible.

RESPIRATORY CENTER INVOLVEMENT

Symptoms indicative of involvement of the respiratory center in the medulla usually appear a number of days after the onset

of paresis of the cranial nerves. Even though the respiratory symptoms are the most striking (18), there is generally some cranial nerve involvement. Irregularities of rhythm and depth of respiration develop in spite of an adequate airway and intact respiratory musculature. The respirations tend to be shallow, and there are often prolonged intervals between inspirations. At this point the patient generally shows some degree of anxiety, restlessness, increased pulse rate and some elevation of blood pressure. These symptoms indicate early hypoxia even though there may be no clinical cyanosis. As failure of the respiratory center progresses, there are increasing periods of apnea with beginning Cheyne-Stokes respiration. The temperature and pulse rate increase, and confusion, delirium and coma soon appear. The periods of apnea become increasingly prolonged until respirations finally cease.

Since these patients have lost the ability to regulate respirations properly, the help of some type of mechanical respirator is necessary just as soon as clinical signs of inadequate ventilation become apparent. The patients often have great difficulty in synchronizing their breathing with the respirator. If this difficulty persists and continues to interfere with ventilation, sedation may be used to suppress the patient's respiration further and enable the respirator to take over breathing almost independently. If the patient is not in a respirator, no sedation of any sort should be given because of the depressant effect on an already damaged respiratory center.

Circulatory Center Involvement

Symptoms of involvement of the circulatory center may be seen to develop concomitantly with evidence of palsies of the cranial nerves (18). In a few instances the circulatory symptoms are the predominant part of the clinical picture.

The clinical symptomatology of involvement of the circulatory center is quite characteristic. The patient's lips are a deep cherry red, and the skin has a flushed, florid appearance. The pulse rate is extremely rapid, ranging from 150 to 200. It is often irregular and at times difficult to palpate. The blood pressure

varies from elevated to low levels, and the pulse pressure may be as low as 10 mm. Hg. In children, the blood pressure tends to become elevated. Very early in the illness, these patients show marked restlessness, apprehension and anxiety, indicating early onset of mild hypoxia. The course generally is downhill. The skin soon becomes cold and clammy and has a mottled cyanosis. The temperature begins to rise and at the same time the respirations tend to become shallow. Terminally, these patients become markedly confused, finally comatose, and the heart beat is inaudible before respirations cease.

Treatment of this type of involvement is very unsatisfactory. It is important to maintain adequate ventilation and oxygenation, with particular attention to maintenance of a clear, unobstructed airway. Supportive measures in combating shock may be used but seem to be of only temporary benefit.

Complications Resulting from Disturbed Respiration

A large number of complications occur in poliomyelitis as a direct result of the disturbance of respiration. It is imperative that the physician be aware of all the possible complications and learn to recognize the symptoms and signs that indicate such processes. Only by early recognition and intensive therapy can the mortality rate from such complications be reduced.

Hypoxia.—Hypoxia plays an important role in the symptomatology of poliomyelitis. The symptoms of hypoxia must be watched for constantly by the physician, and their occurrence must be regarded as a danger sign and an indication for an immediate, thorough check for all factors that may result in deficient oxygenation of the patient. The symptoms of hypoxia as a rule do not occur alone, but are intermixed with those due to actual dysfunction of various parts of the nervous system implicated in the disease. It is for this reason that they are so frequently overlooked. For clarity, those symptoms produced by hypoxia alone and so often seen in poliomyelitis will be described (13). Hypoxia is first manifested by restlessness, apprehension, anxiety and sleeplessness. These patients are keenly

aware that something serious is wrong with them and frequently feel that they are going to die. They require repeated reassurance. Ideas come to them with unusual rapidity, and minimal stimuli produce rapid responses. All movements are extremely rapid as a part of the general hyperactivity. Many patients are unable to sleep and remain awake several days and nights before the hyperactivity subsides.

If the hypoxia is not relieved, the condition becomes increasingly critical. The face becomes flushed and there is a tremor of the hands. The blood pressure becomes elevated and the pulse rate and respiratory effort are accelerated. The patient's anxiety is transformed into a state of euphoria. Speech becomes somewhat limited, the patient saying fewer words in one breath. This second stage of hypoxia is definitely a critical one. If success is to be attained in treatment, the hypoxia must not be allowed to progress beyond this stage, and the causative factors must be discovered and treated.

If allowed to continue, the symptoms progress to the third stage. The patient develops some dyspnea and beginning cyanosis. The temperature continues to rise. The patient now manifests a definite confusional state, often consisting of paranoid projections about members of the nursing or medical staff. These ideas are occasionally replaced by obvious misinterpretations, hallucinations and irrationality. Often this state is accompanied by marked restlessness and even panic reaction. The occurrence of such symptoms of the third stage of hypoxia indicates that the patient's life is in danger. Patients who develop cyanosis as a result of hypoxia rarely do well even after the cause has been discovered and the symptoms relieved.

If the hypoxic syndrome is allowed to continue, the fourth and final stage develops. The dyspnea and cyanosis become more intense. There develop quivering, trembling, twitching and jerking of the facial muscles and, to a lesser degree, of the extremities. Confusion continues and the patient does not comprehend or answer questions. The temperature continues to rise and the patient soon becomes lethargic, comatose and passes into terminal shock.

When symptoms of hypoxia develop in poliomyelitis, the phy-

sician must immediately seek the cause of the deficiency of oxygenation and, if possible, remedy it. The common causes of deficient oxygenation are: (1) obstruction of the air passages by secretions or food, by paresis of the vocal cords or by reflex spasm of the glottis; (2) failure of the peripheral or central respiratory mechanism; (3) failure of circulation; (4) pulmonary complications, especially atelectasis, pulmonary edema or pneumonia, and (5) failure of mechanical devices, such as poor positioning of tracheotomy tube, fluid in tracheotomy tube or leakage in portholes or collar of respirator.

ACID-BASE BALANCE.—The normal blood pH is 7.4. This value is maintained by a balance between acid and base of the blood, regulated in part by carbon dioxide exchange in the lungs. With hyperventilation that occurs with too rapid excursions in a respirator, carbon dioxide is lost and there is also a drop in the normal bicarbonate levels of the blood. Normally there result a compensatory depression of respiration and an excretion of bases in the urine, thus restoring the proper acid-base balance. If the patient is in a respirator where such a respiratory depression is impossible, the respiratory alkalosis may continue, resulting in severe neurologic complications or even death. Respiratory alkalosis can produce symptoms closely resembling those of hypoxia. Nausea, restlessness, mild confusion, twitching of the musculature and lethargy may develop. If not remedied, the patient passes into terminal coma.

Respiratory acidosis can result from a large number of complications of poliomyelitis, including: (1) pulmonary edema, atelectasis and pneumonia; (2) intercostal or diaphragmatic paralysis; (3) injury to the respiratory centers. In the first two situations, there is a disturbance in the removal of carbon dioxide from the blood due to inadequate pulmonary action. Ordinarily, as carbon dioxide accumulates in the blood, the respiratory center is stimulated, leading to an increase in the respiratory rate. Both injury to the respiratory center and the use of the respirator will interfere with this compensatory mechanism, resulting in an increase of the respiratory acidosis. In such circumstances, the partial pressure of carbon dioxide of the blood continues to rise, the chlorides decrease, and the urine be-

comes acid in an attempt to reduce acidity of the blood. The patient rapidly loses consciousness and will die unless the acidosis is relieved.

Because of the rapid fluctuations in acid-base balance, it is important to check the bicarbonate, potassium carbonate, sodium and chloride values and the reaction of the urine daily in patients who are severely ill with bulbar poliomyelitis, particularly those in a respirator. Adjustments must be made in the rate and depth of the respiratory excursions according to the acid-base balance. It is important to attempt to keep the values of the blood sodium and chlorides as normal as possible.

Vomiting.—In patients with poliomyelitis, vomiting may develop from many causes. If vomiting persists for 24 hours or more, or if gastric suction is applied for the same period, grave complications may result from a disturbance of the acid-base balance. During vomiting or gastric aspiration there is a loss of fluids as well as electrolytes. A patient can lose nearly 8 L. of fluids in 24 hours, or almost one-fifth the total body water. In addition, approximately 40–50 Gm. of salt per day may be lost, which is almost half of the total body salts and almost five times the daily intake. The gastric juice contains 145 mEq. per liter of chlorides but only 15 mEq. of sodium, so that the greater loss will be in the chlorides. As a result of the fluid and electrolyte losses from vomiting, a number of body changes occur. (1) The extracellular fluid is reduced. (2) Metabolic alkalosis develops because the sodium formerly bound to the chlorides is free to combine with the carbonate because of the loss of chlorides. (3) The kidneys excrete an alkaline urine in an attempt to compensate for the alkalosis.

In every case of vomiting, the electrolytes and fluids lost should be measured and replaced. It is possible to replace most of these losses by the administration of saline intravenously or by stomach tube.

Poliomyelitis of Higher Centers

Hyperthermia.—Neurogenic hyperthermia can result from damage to the hypothalamus in poliomyelitis (21). Apparently it is the anterior hypothalamus that is active in reducing body

temperature and its injury will allow the development of hyperthermia. Since the hypothalamus is frequently and consistently involved in most cases of bulbar poliomyelitis (22), one can anticipate that a number of patients will have instability of the temperature-regulating mechanism, and every precaution must be observed to prevent or to minimize excessive temperature elevations which may complicate the care of these very ill patients. In patients acutely ill with such a severe infection as poliomyelitis, often complicated by pulmonary or urinary involvement, evaluation of the significance of hyperthermia is often difficult. Most patients with bulbar poliomyelitis have a very high terminal temperature, and many have a fairly high temperature at the onset of the illness. However, in a number of cases the hyperthermia is out of proportion to the severity of the illness and often comprises the predominant symptom. In some patients, the hyperthermia continues throughout the illness and resists all efforts at reduction. Many of these patients show no evidence of any secondary infection which might account for the elevated temperature.

In such patients, the use of hot packs must be avoided, and if the patient is in the respirator every attempt must be made to keep him cool by use of ice bags and cooling devices. Once the body temperature rises, every means should be employed to reduce it. Antipyretics generally are not very effective. Alcohol sponges, ice packs and sponges with cold water may be helpful. If possible, the patient should be kept in an air-conditioned room until the body temperature becomes stabilized.

GASTRIC HEMORRHAGE.—Because of hypothalamic involvement in poliomyelitis, specific gastrointestinal lesions occur and may play an important role in the ultimate outcome and recovery of the patient (23). During the acute illness, lesions consist primarily of petechiae, ulcerations and hemorrhage. Early, the patient may complain only of mild abdominal pain or abdominal distention. Many patients refuse food because of the discomfort it produces. At this stage, bleeding is probably mild and no doubt associated with some ulceration. As the bleeding continues, the patient becomes nauseated and vomits small amounts of "coffee-ground" material. Generally at this time there is no

alteration in the hemoglobin and no evidence of shock. However, the gastrointestinal complaints and sudden appearance of "coffee-ground" emesis should suggest the possibility of gastric bleeding and demand investigation for such a complication.

More intense hemorrhage results in marked abdominal distention and the emesis of large amounts of blood which may be "coffee-ground" or even bright red. The blood pressure may fall to shock levels, and there is a rising pulse rate. In a number of instances, the first indication of such a complication is the sudden appearance of symptoms of shock in a patient who has been doing fairly well. The pulse suddenly becomes feeble and rapid, the blood pressure drops, and the skin becomes cold and clammy. With the onset of these symptoms, the patient occasionally may lose consciousness or become confused, apprehensive or restless.

Gastric hemorrhage must be included among the more serious complications of acute bulbar poliomyelitis. Severe hemorrhage may be the immediate cause of death, so its early recognition and treatment may prevent shock and death. Less severe bleeding, although not responsible for immediate death, may play a role in the unfavorable course of the illness. Certainly tissues already damaged by the infectious process may be more severely damaged or even destroyed as a result of decreased nourishment secondary to the loss of blood.

The usual treatment for bleeding from a gastric ulcer is followed. The patient is given transfusions of whole blood, each consisting of 500–600 cc. If the patient is not vomiting, feedings of milk and cream may be instituted fairly promptly, generally by a continuous slow drip through an inlying nasal tube over the 24 hour period. Other antacids may be used, as well as methantheline (Banthine).

GASTRIC DISTENTION.—This form of gastrointestinal disturbance is not usually seen in the very acute illness but appears during convalescence. At onset the patient may complain of a loss of appetite and some nausea and vomiting. Generally, the vomitus contains only mucus. In the more severe cases, the patient has severe abdominal distention and often acute abdominal pain. In patients with limited respiratory reserve, particularly in those who have weak diaphragmatic action, this distention may further

limit respirations and produce acute respiratory embarrassment which may be fatal if not recognized and remedied. These deaths are particularly tragic because they are easily prevented simply by aspirating the stomach and thus relieving distention.

INVOLVEMENT OF HEMISPHERES.—The cerebral hemispheres are involved in about 75 per cent of cases of bulbar poliomyelitis. The lesions usually are localized to the motor cortex, involving primarily the third and fifth cortical layers (24). In many patients with bulbar poliomyelitis, there is an additional hypoxic factor which often results in a more diffuse neuronal damage that implicates all areas of the brain and produces more widespread symptomatology. The symptoms include headache, anxiety, restlessness, hyperexcitability, muscle tremors and twitchings, confusion, hallucinations, lethargy, coma and convulsions, especially in children. There may be marked insomnia and hyperexcitability and the other manifestations described in the discussion of hypoxia. These patients have a pronounced urgency about getting rid of pharyngeal secretions, about having the pillows rearranged or about having the tracheotomy tube adjusted.

In some cases the encephalitic picture is manifested chiefly by the sudden onset of intense headache followed by lethargy or even deep stupor. The degree of somnolence bears no relation to the height of the fever or the severity of the systemic illness. The neurologic findings are most variable. The deep reflexes are often hyperactive but may be unequal, or even reduced. The toe signs may be present. Motor weakness, if present, is generally of the lower motor neuron type. The relationship of hemiplegia to poliomyelitis is very uncertain. In most large epidemics of poliomyelitis, hemiplegia is not observed, and it is questionable whether the so-called hemiplegic type of poliomyelitis actually exists.

The cerebellum is frequently involved pathologically in poliomyelitis even though clinical manifestations of such involvement are uncommon (25). Ataxia has been mentioned as a complaint in many large epidemics of poliomyelitis. Generally, cerebellar symptomatology is uncommon, but when it occurs it consists of nystagmus, vertigo, intention tremor and ataxia.

When cerebral symptoms appear in poliomyelitis, they should first be considered as being due to hypoxia, even if there is no cyanosis, and the causative factor sought. Once the exact causative factor has been discovered, appropriate therapy can be instituted. Only when cerebral symptomatology persists after adequate ventilation is achieved can one ascribe the cerebral symptoms to an actual involvement by the virus or irreversible damage by the hypoxic process. In either case treatment must be symptomatic, since most of the symptoms will improve as the patient recovers. In these cases, attention must be given to adequate nutrition and the prevention of exhaustion due to overactivity.

VACCINE IN POLIOMYELITIS

In 1949 Enders and his associates (26) demonstrated that the poliomyelitis virus could be grown and isolated in vitro on nonnervous tissue cells and that human or monkey kidney was one of the best tissues for this purpose. By the use of monkey kidney tissue growing in vitro, Salk proceeded to grow large quantities of all three types of poliomyelitis virus. He was then able to obtain sufficient amounts of virus to proceed to the development of a vaccine by killing the virus with formaldehyde. This killed vaccine composed of all three virus types was given to a large number of monkeys and produced a good antibody titer against all types of poliomyelitis and protected against infection with these viruses.

Ideally, the Salk vaccine should be given at monthly intervals for the first two inoculations, then the third inoculation is postponed for at least seven months. In man this vaccine, when antigenically potent, after the third inoculation, produces antibody levels comparable to those of natural infections. Salk feels that the antibody response is greatest when the third inoculation is delayed for from seven to ten months. It must be kept in mind that the complexity of the preparation of this vaccine has led to a considerable variation in the antigenic potency of different lots of vaccine and a consequent variability in the degree of protection. This defect no doubt will soon be remedied. It is generally accepted that the vaccine is safe. However, it will be years before

it is known just how long immunity lasts. It should also be remembered that many investigators are working on other methods of vaccine preparation which may make available in the near future a vaccine superior to that now available.

Another result of tissue culture growth of the poliomyelitis virus has been a rapid method of identifying the infection and of determining the type of virus producing the disease. This can be done by direct inoculation of tissue cultures with stools of ill patients. Virus growth is manifested within 24 hours by a breakdown of the growing tissue culture cells. By inoculating the tissue cultures with immune sera from the various types of poliomyelitis virus, one can also determine the virus type by the specific neutralizing effect of the corresponding immune serum. This method of diagnosis is now being used with increasing efficiency and frequency.

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